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ERS- SAR ANI) SSM/I DATA IN THE GREENLAND SEA ODDEN REGION USED WITH NUMERICAL SIMULATIONS TO 1DICN'J'JF% ANI) MONITOR OCEAN CONVECTION

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1. introduction

Ocean convection is a climatically important process in which air-sea interactions influence oceanic circulation through the ventilation of deep and intermediate walers. A key site of convection, active in at least some winters, is in the Greenland Gyre, and the convection seems to be related to the development of an ice feature called Odden ("the Icy Cape" in Norwegian), an eastward extension of the ice edge in the latitude range 710 to 75°N. Previously published results from the 1988-89 winter (GSP Group, 1990; Roach cl al, 1993) showed that intermediate-depth convection near the Odden ice edge at 75°N, 4 'W immediately precede the formation of the "Nordbukta", a rapid ice retreat which occurs in nearly every winter. Wc conclude, therefore, that the cold brine from Odden formation is related to the establishment of this convection and that the Nordbukta retreat is the consequence of that convection.

The key dynamic elements of oceanic convection are the individual plumes, the clusters of plumes called chimneys, the eddies that arc the consequence of chimneys aging in a rotating frame, and the embayments and pol ynyas result ing from the spread of Al W convective return water on the surface. Recent numerical work, which has not included surface wind dynamics, has suggested that plumes, of dimensions about 100-300 m (Jones and Marshall, 1993; Garwood, 1991; Gascard, 1991) cluster in chimneys of scale 10-60 km, Theoretically these chimneys arc expected to grow through increase in the number of plumes, decay through baroclinic instabilities, and to circulate cyclonically with lhc gyre.

In this paper wc discuss these features as seen in satellite data. Specifically wc present an interpretation of coarse, resolution passive microwave data for 1989 and 1992 in the context of a simple model of ice-edge retreat to obtain the Nordbukta embayment growth and the formation and migration of an Odden polynya. These features are controlled, wc assume, by the propagation of convection and the presence of convective-return water at the surface. We also present fine resolution ERS-1 SAR data which describes the surface structure of what appears to be convecting plumes. While, wc cannot state with certaint y, wc speculate that the 1992 convection is not deep.

I'here is a temptation to think that the Odden ice growth simply removes the fresher surface. PW by brine generation, but this is not the case. The Bourke et al (1992) section shows a surface salinity change of about 1 psu/100 km; to remove this layer by brine from ice growth with the surface. fluxes available. is not practical. Using a mean flux of 200 watts/m^2 and a mixed layer of 50 m thickness, the retreat of the edge of fresher layer, and thus of the ice edge, would occur at a maximum (if all heat 1OSL at the surface is latent heat, which it is not) of only 3 km/day, 20% of the observed rate (Roach et al, 1993, and below). The heat and brine in the convective.-rcturn Al W is essential.

2 The Convective Events of 1989 and 1992

As part of the Greenland Sca Project, oceanographic data from the upper 200 m at two locations were examined (Roach et al 1993; scc also Schott et al, 1993). The growth of sca ice, in the central Greenland gyre increased the salinity of the upper water column locally and reduced the vertical stability profile during December and January. Subsequent cooling increased the density of the surface waters to a critical point and a cold air outbreak in late January 1989 provided enough buoyancy loss to convectively overturn at least the upper 200111, Replacement water then rose. from the warmer pool of intermediate water at mid-depth causing an increase in the heat available in the upper layer. The surface signature of that warming was the retreat of the icc cover near GSP-4 and then along the Greenland shelf edge to the south west, where the warmer water apparentl y was advected.

A convective overturn of the central Greenland gyre occurred about January 20 (Roach et al ,1993) the 1989, and shortly thereafter an embayment forms at the ice edge in the upper center of Odden, and the embayment grows by steady icc retreat of 10-15 km each day to the southwest. the retreat continues steadily until about day 66 when there is some episodic advance and retreat, A persistent tongue of ice is seen to lie along the axis of the Jan Mayen Current as observed by Bourke et al (1992). Near day 30, three scallop shaped features appear in the ice. edge and move approximatel y to the southwest. We initially took them to be the, chimney features as discussed by both theoretical (Jones and Marshall, 1993) and observational (Gascard, 1991) investigators, although the scale, of the. scallops is some 60-100 km, larger than has been discussed. Another difficulty in the identificat ion of the scallops as chimneys is that chimney drifts should retain the cyclonic sense of the gyre while the, scallops simply move to the southwest at the rate of the Nordbukta retreat.

A scallop which appears on the eastern side of the convective embayment dots not simply move SW on the embayment fringe as the others do; it c1oscs into a migrating open-water feature which wc argue is basically a convective scnsib]c-heat polynya of 60-90 km diameter. There is a persistence in the polynya formation; when it has moved some 120 km to the SW of its formation another scallop forms at its origination site,. The migrating polynyas "fill" with icc when the fresh PW water from the Jan Mayan Current terminates the convection. 'l'his eastern feature., which wc will call the eastern polynya, thus has a distinctive behavior, and its characteristics may be indicative of some. aspects of the Odden convection. All the scallops move at within 10% of the same rate. and arc. thus likely to be controlled by a common mechanism. At the same time, this tendency to move to the southwest is not universal to Oddcn-area features; the far northeast edge of Odden, for example, moves to the north-cast; its behavior is uncorrelated with the embayment features.

3. Odden Ice Cover Behavior

The rapid icc retreat has been attributed to the action of heat brought to the surface by the convective-return AIW (Roach et al, 1993). The first question to address deals with the. rate of icc retreat, From visual inspection the icc rc.treat has a rate of about 12 km/day. The chimney growth rates suggested by theoretical analyses arc 2.-3 km/day (1 ,cgg and Marshall, 1993), and the currents of the region arc. negligible (Roach et al, 1993). Thus wc have onl y the wind as external force for the rapid icc edge retreat. If wc speculate that the convective-rclurn water terminates new icc formation exactly, i.e., no icc cover is formed or cleared after the convection begins, then the last ice that formed will move under simple wind forcing, and it may continue to thicken under surface heat loss. According to Moritz (1988),

$$U - c = BG \qquad (1)$$

where U is the (complex) icc velocity, c is the current, G is the geostrophic wind, and B is a complex constant which contains the drag coefficient and Coriolis turning. We will usc c = O. Further, wc will concern ourselves only with the icc motion component down the center of the Odden box. Following Moritz (1988) wc usc

$$|B| = 1.21\text{x } 10^{-2}$$
$$\Theta = \arg(B) = -3° \qquad (2)$$

In the above wc arc specifically modeling icc motion, but the modeling of the motion of warm surface Al W would usc equivalent terms. Thus, wc arc examining the motion of the icc edge to scc if it is controlled by wind-drive.rr properties. The measured icc edge retreat velocity component by both SSM/I and the wind-forced calculation arc similar enough that wind advection of surface waters and sca icc likely plays a role in the formation of the Nordbukta, but wc cannot say whether icc at the edge is moving a bit faster than or more slowly than the edge itself, or if the icc itself might be growing or becoming thinner near the edge.

The closing of the eastern scallop into a polynya is significant. The central retreat could easily be driven entirely by a convcclivc-return water source limited in geographic extent to the region immediately around the gyre center; the convcclivc-return water would simply be blown downwind to 1osc heat to the. air and mix with surface. and near surface walers. However, the eastern polynya has to bring its convective-return water source along with it as it moves to the southwest down the box. Additionally, since icc is found all around it, there must be a source. of fresh water at the surface, behind it, and the. only source of fresh water is mch-watt.r. '1'bus, the eastern pol ynya is apparently moving a bit more slowly than the ice itself so that ice is steadily melting at the polynya upper edge. Consequently ice is always forming at the lower edge of the polynya and, presumably, generating brine for the. maintenance of convection. If the SW edge of the central retreat acts in the same manner as the SW edge, of the pol ynya, then convective waler is located in the southern cad of the open water area less than 100 km from the ice. edge.; the remainder of the large embayment of the. central retreat is simply Al W of convective-return origin which is mixing in a turbulent fashion as pointed out by Schott et al, (1993),

4. Convective Plumes in SAR Data and Simulations

The kcy element of oceanic convection, the active plume, has as yet not been convincingly observed or simulated. Some data has been acquired: from the temperature series on GSP 4 during the convective period, an upper bound on the vertical velocity of 3.1 cm s] was noted. This is in general agreement with vertical velocities measured directly by Doppler profilers in the Mediterranean Sca and in the Greenland Sca (Scholl et al, 1993). Jones and Marshall (1993) and Garwood (1991), through scaling arguments, have found the important terms in the convective process arc buoyancy flux, Coriolis force and ocean depth, The Jones and Marshall (1993) calculations applied to our data with a maximum 500 W m^{-2} heat loss yield a plume of about 160 m wilh a vertical velocity of 2.2 cm s] while the Large Eddy Simulation (1 .ES) approach (Garwood, 1991) finds similar plume scales and that the plume array should have spacing dependent on convection depth and ranging up to 2 km for deep convection in the Greenland Sea. Wc show and discuss ERS- 1 SAR data and modeling results hypothesized to represent modeled and observed plume surfaces. The (hypothesized) convecting region is seen to be about 20 km by 90 km and to be located directly north of the Odden icc edge. According to the ECMWF wind analysis for this area, the date of the SAR image, Feb. 12, 1993, was a day of very low winds, about 2 ms^{-1}; in more usual wind conditions the plumes might have a very different appearance, or they might be not visible in SAR images at all.

5. Conclusions

Wc tentativel y conclude that the central retreat has convection, probably to shallow or intermediate depths, al work only in a small region (≤ 100 km) near the ice edge, and it is characterized over most of the o]wn-water area by a well mixed layer at least 200 m and possibly 500 m deep. Wc would expect to find similar plumes in the migrating polynyas in Odden. Wc have no model or strongly -indicative data on the mechanism for the propagation or wind-advection of convecting water, but the indirect evidence that the icc and the convecting watt.r arc not moving at the same rate discourages a simple wind-driven approach even though small velocity differences for different ice types or surface waler could certainly be expected. These tentative conclusions require rnorc data, from both satellite and in-situ platforms, and the observations should be used to advance the modeling work as well.

6. References

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